AMERICAN JOURNAL OF PHYSICAL ANTHROPOLOGY 109:245–252 (1999)

Sexing Potential of Fragmentary and Pathological Metacarpals

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KEY WORDS metacarpals; sex assessment; forensic anthropology

ABSTRACT The use of metacarpal dimensions for determining skeletal sex is investigated. Previous studies on sexual dimorphism in the metacarpals (Scheuer and Elkington [1993]; J. Forensic Sci. 38:769–778; Falsetti [1995]; J. Forensic Sci. 40:774–776; Smith [1996]; J. Forensic Sci. 41:469–477) used multiple variables, which limits the application potential of the methodology. Using six measurements for each metacarpal, I generated 35 linear discriminant functions based on expected taphonomic or pathological preservation scenarios. The number of variables per function ranged from 2–5. Normal, jackknifed, and cross-validation classification matrices indicated a sex prediction accuracy in the 79–85% range. MC4 produced the most consistent functions. Overall accuracy in the validation samples ranged from 75–90%. ANOVA and MANOVA analyses indicated that population effects are insignificant, which may allow for the application of the functions without knowledge of the ancestral background of the individual. This, combined with the variety of preservation scenarios considered, provides accurate sex estimators for incomplete individuals. However, the population specificity of the insignificant population group effects remains untested. Am J Phys Anthropol 109:245–252, 1999.

Several recent studies reported on the sex assessment potential of metacarpal dimensions. Scheuer and Elkington (1993) utilized a sample of 60 individuals of British ancestry and generated regression equations based on six metric measurements for the five metacarpals and the first proximal phalanx. The six measurements included: interarticular length, midshaft maximum diameter, antero-posterior and medio-lateral base breadths, and antero-posterior and medio-lateral head breadths. A random holdout sample of 20 individuals was utilized to independently validate the classification functions. Sex prediction accuracy ranged from 78% (MC2) to 94% (MC1).

Following this, Falsetti (1995) generated linear discriminant functions based on five measurements for the five metacarpals. Metacarpal length, head medio-lateral breadth, and base medio-lateral breadth were recorded as defined by Scheuer and Elkington (1993). Falsetti (1995), however, omitted the antero-posterior end breadths and divided the maximum midshaft diameter into two separate variables, antero-posterior midshaft breadth and medio-lateral midshaft breadth. Falsetti utilized the Terry collection (n = 212) and tested for populational differences between European-Americans and African-Americans using a two-way ANOVA. Metacarpals 2, 4, and 5 did not exhibit populational differences in morphology, and population-free functions were generated for these elements only. The functions were derived from the Terry sample and then independently validated using a sample of 33 individuals from the Royal Free Medical School (London, UK) and a

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Received 21 September 1998; accepted 1 March 1999.

sample of 40 individuals from the University of New Mexico (UNM) documented collection. The former sample was classified with an accuracy of 57% (MC2) to 85% (MC4). The latter sample was classified with an accuracy of 78% (MC2) to 85% (MC5). Falsetti (1995) concluded that the functions for metacarpals 2, 4, and 5 may provide a useful alternative method for sex assessment when the populational affinity of the individual is unknown.

Smith (1996) analyzed a series of hand bones from the Terry and Huntington collections (National Museum of Natural History, Washington, DC) for the purposes of sex and population group prediction. In addition to metacarpal dimensions, Smith (1996) used data from the proximal, middle, and distal phalanges. Stepwise discriminant analysis was utilized to omit extraneous, highly correlated measurements to reduce the number of variables. Sex prediction accuracy ranged from 89% for the left hand metacarpals to 72% for the right hand metacarpals; phalanges were correct approximately 80% of the time. Functions developed for the purpose of population group allocation were successful approximately 80–98% of the time.

While these previous investigations are extremely useful, there are several reasons why the published functions may not be appropriate for use on modern American forensic cases. The use of a British control sample (Scheuer and Elkington, 1993) may be problematic for forensic applications in the United States (Lazenby, 1994). Falsetti (1995) addressed this problem by generating functions based on American material, i.e., the Terry collection. However, the Terry collection may also be inappropriate if secular increases in metacarpal dimensions occurred between the Terry sample and truly modern individuals (see Meadows and Jantz, 1995). The use of the Huntington collection may be similarly problematic, particularly given its recent immigrant demographic composition (Smith, 1996). Secular changes in skeletal morphology of immigrant groups is a well-known phenomenon (Boas, 1912). Similarly, since the assessment of differences in population-specific metacarpal morphology was performed on the Terry sample, it is uncertain whether similar differences exist in modern populations. Of course, Falsetti could not have known this since these studies were published concurrently. Smith (1996) also reported significant population group separation; however, here again these findings were based on older skeletal samples.

Sampling aside, Scheuer and Elkington (1993), Falsetti (1995), and Smith (1996) generated functions based on multiple measurements. This results in an "all or nothing" situation, since the method requires that all measurements are available. This is somewhat contradictory given the fact that the use of metacarpals for sex assessment will likely only occur in fragmentary examples. Therefore, it seems likely that incomplete or slightly damaged elements are more likely to be utilized. My personal observations in the UNM documented sample indicate that deterioration on the anterior tubercles is fairly common, making the medio-lateral dimensions unavailable. In addition, metacarpals with poorly healed fractures negate the length and midshaft measurements; however, this may not be a common occurrence in contemporary populations. Perhaps more problematic are arthritic modifications on either the proximal or distal ends that make the measurement of the end breadths difficult. Smith (1996) noted similar problems with arthritic lipping in a sample of individuals from the Terry and Huntington collections.

In this study, I reevaluate the sexing potential of the metacarpals and generate functions based on a truly modern control group. In addition, I develop linear discriminant functions based on expected preservation scenarios and pathological conditions, which will allow for a broader range of potential application. Population group effects are further evaluated in the UNM documented collection.

MATERIALS AND METHODS

In this study I utilize the UNM documented collection as the control sample. This sample contains the defleshed remains of approximately 200 individuals of known age, sex, and population affinity. The majority of remains were donated to the Maxwell Museum of Anthropology (Albuquerque, NM)

as part of an ongoing body donation program. All individuals in the control sample were born post-1900. Both European-Americans and African-Americans were included in the control sample. The exact sample composition for each function varied due to differences in preservation, pathological condition, and element representation. However, the maximum sample divided as follows: 55 European-American males, 22 African-American males, 30 European-American females, and 15 African-American females. The within-population sex ratio was approximately equal, avoiding problems of sample size effects in multivariate hypothesis testing.

I recorded six measurements for each metacarpal as defined by Scheuer and Elkington (1993). Exact descriptions and measurement protocols can be found in that publication and are not repeated here. The six measurements included: midline interarticular length, maximum midshaft diameter, medio-lateral and antero-posterior head breadths, and medio-lateral and antero-posterior base breadths. All measurements were taken with a pair of digital sliding calipers and rounded to the nearest tenth of a millimeter. The calipers were zeroed between measurements to ensure accuracy. The left side was recorded (see Lazenby, 1994). All measurements were taken by the author so that interobserver error would be negligible for this study. Lazenby (1994) conducted limited analyses of intraobserver repeatability for the second metacarpal and found the differences between measurements to be small and not statistically significant.

The two principle statistical treatments included MANOVA and discriminant analysis, both of which assume equal sample covariance matrices and multivariate normality. I first tested for populational differences in the six measurements for each metacarpal, using ANOVA and MANOVA analyses. I evaluated the assumption of univariate normality for the ANOVAs using the Wilk-Shapiro test. The assumption of equal sample variances was evaluated with the F-test. Multivariate normality was evaluated using Mardia's multivariate skewness and kurtosis test (Mardia, 1970). I evaluated the assumption of equal sample covariance matrices using the Proc Discrim procedure in Batch SAS, which generates *P*-values for a chi-square distribution based on Bartlett's generalization of the likelihood ratio test (SAS Institute, 1996). All tests were performed with population as the grouping variable. I controlled for familywise error with Bonferroni alpha protection. The above procedures were then repeated, using sex as the grouping variable to evaluate the assumptions of the discriminant analysis.

Since the purpose of this study was to develop discriminant functions for multiple combinations of metacarpal dimensions, illogical preservation scenarios, such as a measurable midshaft but an immeasurable length, were avoided. Independent functions were generated for isolated articular ends based on the antero-posterior (AP) and medio-lateral (ML) dimensions. Similarly, a function was generated for an intact head and base with no measurable length or midshaft. This would include elements suffering from postmortem breakage as well as a poorly set premortem fracture. Finally, one of the most common situations I encountered in the UNM sample was an almost complete element which exhibited minor damage to one of the four articular surface dimensions. This category also included elements which exhibited moderate arthritic changes on a single articular surface. The overall small scale of these variables made even minor deterioration or arthritic lipping significant. Four separate functions were developed for each of these four scenarios.

I selected a random sample of approximately 40 males and 40 females as the calibration sample to generate the classification functions. This effectively controlled for the prior probabilities and gave equal weight to both sexes. Normal and jackknifed classification matrices were recorded as a measure of sexing accuracy. However, the normal matrix was obviously biased, as the observations being classified were also used to generate the group centroids. The jackknifing procedure negated this bias, resulting in a slightly lower, yet more realistic, classification percentage. However, the corresponding function for the jackknifed matrix could not be determined, since in reality

TABLE 1. ANOVA and MANOVA P*-values assessing populational and sexual differences in metacarpal dimensions*

	MC1		MC2		MC3		MC4		MC5	
Measurement	Pop.[1]	Sex	Pop.	Sex	Pop.	Sex	Pop.	Sex	Pop.	Sex
ANOVA[2]										
Length	.45	.0001	.69	.0001	.38	.0001	.82	.0001	.81	.0001
Base AP[3]	.12	.0001	.37	.0001	.37	.0001	.80	.0001	.31	.0001
Base ML[3]	.60	.0001	.45	.0001	.98	.0001	.80	.0001	.91	.0001
Head AP[3]	.19	.0001	.13	.0001	.82	.0001	.59	.0001	.91	.0001
Head ML[3]	.89	.0001	.85	.0001	.56	.0001	.40	.0001	.15	.0001
Midshaft	.01	.0001	.21	.0001	.53	.0001	.99	.0001	.54	.0001
MANOVA[4]										
Pop. Effect	.1726		.1383		.6768		.7238		.5901	
Sex effect	.0001		.0001		.0001		.0001		.0001	

[1] Pop., population group.
[2] Alpha protection for within element, within effect at $P \leq .05 = P \leq .008$.
[3] AP, antero-posterior; ML, medio-lateral.
[4] Includes Wilk's lambda, Pillai's trace, Hotelling-Lawley trace, and Roy's greatest root.

it was not a single function but $n - 1$ functions. The preferred method of cross-validation is the classification of a random holdout sample. In this case, the attempt to control for sample sizes in the calibration sample resulted in a disproportionate sex ratio in the validation sample. Since females are underrepresented in the UNM collection, they comprised a small percentage of the validation sample. Similar problems with female cross-validation have been reported elsewhere (Meadows and Jantz, 1992). The ANOVA and MANOVA procedures were performed in Batch SAS on the University of New Mexico's Unix system. The discriminant analysis was generated with Systat for Windows version 7.0 (Wilkinson et al., 1996).

RESULTS

The assumption of univariate and multivariate normality was evaluated using the Wilk-Shapiro and Mardia's multivariate skewness and kurtosis tests (see Mardia, 1970). All Wilk-Shapiro *P*-values were insignificant. Several samples exhibited nonnormal skewness statistics; however, observations of the box plots indicated that the effects of the degree of skewness should not have radically affected the MANOVA procedure. The assumption of equal sample variances was verified with the F-test. Equal sample covariance matrices was verified using Bartlett's test for covariance homogeneity (SAS Institute, 1996). All tests were insignificant.

Population effects were evaluated using a MANOVA which included both a sex and population effect for the univariate samples and an overall population and sex effect for the combined variables for each metacarpal. This tested for univariate population effects as well as population effects for the combination of six measurements for each metacarpal. I report the *P*-values for the F-tests in Table 1. All univariate tests for populational differences were not significant when the Bonferroni correction was utilized. All univariate tests for sex effects were significant after adjusting for familywise error. The MANOVA *P*-values are also included in Table 1. Once again, overall population effects were negligible for each metacarpal, while sex effects were significant. It appears that the population effects reported previously for MC1 and MC3 (Falsetti, 1995) did not occur in this particular modern sample. All discriminant functions were generated without regard to population affinity. It should be stressed, however, that just because population effects were insignificant in this sample, this does not mean that all modern samples will be similarly homogenous in regards to population affinity.

Discriminant analysis assumes that the cross-sample covariance matrices are equal and that the within-sample distribution is multivariate normal. The sex-specific covariance matrices for all five metacarpals did not differ significantly. Multivariate normality was assessed using the test of Mardia (1970). In general, kurtosis was not a problem; however, several samples exhibited nonnormality for the skewness statistic. Only

TABLE 2. MC1 discriminant function coefficients and constants

Measurement	1	2	3	4	5	6	7
Length				.106	.127	.146	.155
Midshaft				.235	.086	.131	.190
Base AP[1]	.650		.451		.436	.491	.520
Base ML[1]	.367		.017	.021		−.146	−.042
Head AP[1]		.569	.208	.244	.047		.095
Head ML[1]		.605	.365	.358	.265	.299	
Constant	−15.62	−14.79	−15.84	−16.76	−18.12	−17.91	−17.63

[1] AP, antero-posterior; ML, medio-lateral.

TABLE 3. MC2 discriminant function coefficients and constants

Measurement	1	2	3	4	5	6	7
Length				.084	.091	.084	.082
Midshaft				1.006	1.047	.996	.943
Base AP[1]	.408		.294		−.010	.052	−.023
Base ML[1]	.467		.314	.121		.179	.075
Head AP[1]		.471	.214	.252	.288		.234
Head ML[1]		.597	.184	−.157	−.092	−.101	
Constant	−15.04	−15.94	−16.39	−18.17	−18.26	−17.13	−18.37

[1] AP, antero-posterior; ML, medio-lateral.

TABLE 4. MC3 discriminant function coefficients and constants

Measurement	1	2	3	4	5	6	7
Length				.084	.072	.067	.066
Midshaft				1.037	.937	.951	.813
Base AP[1]	.784		.573		.296	.362	.258
Base ML[1]	.312		.162	.166		.061	.019
Head AP[1]		.520	.278	.337	.256		.176
Head ML[1]		.467	.114	−.206	−.207	−.101	
Constant	−17.83	−14.21	−17.76	−19.02	−18.87	−18.56	−18.82

[1] AP, antero-posterior; ML, medio-lateral.

TABLE 5. MC4 discriminant function coefficients and constants

Measurement	1	2	3	4	5	6	7
Length				.133	.128	.146	.122
Midshaft				.681	.839	.735	.609
Base AP[1]	.009		.007		.005	.006	.006
Base ML[1]	1.030		.441	.255		.402	.284
Head AP[1]		.931	.642	.402	.551		.365
Head ML[1]		.331	.248	−.094	−.131	.037	
Constant	−12.46	−15.96	−16.65	−19.43	−18.73	−18.92	−19.42

[1] AP, antero-posterior; ML, medio-lateral.

MC5 exhibited multivariate normality for both samples. However, multivariate nonnormality does not, by default, negate the accuracy of the function as an estimator; rather, it confounds the determination of the significance between the group differences (Manly, 1994). It is possible for samples to exhibit nonnormality and unequal covariance matrices yet still be classified accurately with a linear discriminant function. In many cases, these assumptions are unrealistic, and hence the tendency to ignore them in the literature.

I generated seven discriminant functions for each metacarpal according to the preservation scenarios described above. I present the function coefficients and constants for MC1–5 in Tables 2–6. All functions have been set equal to zero so that a score above zero is sexed as male and a score below zero is sexed as female. The normal, jackknifed, and cross-validation matrices are presented

TABLE 6. MC5 discriminant function coefficients and constants

Measurement	1	2	3	4	5	6	7
Length				.134	.168	.155	.142
Midshaft				.162	.292	.114	.138
Base AP[1]	.596		.220		.375	.390	.278
Base ML[1]	.862		.703	.624		.621	.603
Head AP[1]		.701	.388	.429	.334		.252
Head ML[1]		.597	.220	.050	.109	.091	
Constant	−18.39	−15.35	−19.31	−22.38	−20.15	−22.78	−22.69

[1] AP, antero-posterior; ML, medio-lateral.

TABLE 7. MC1 normal, jackknifed, and validation sample classification matrices

Matrix type	1	2	3	4	5	6	7
Normal (from-into)							
male-male	33	32	30	32	38	31	30
male-female	6	7	8	6	8	7	8
female-male	4	3	3	4	3	3	4
female-female	27	29	26	25	26	26	25
% accuracy	86	86	84	85	84	85	82
Jackknifed (from-into)							
male-male	33	31	27	29	28	29	28
male-female	6	8	11	9	10	9	10
female-male	4	3	4	4	4	4	5
female-female	27	29	25	25	25	25	24
% accuracy	86	85	78	81	79	81	78
Validation (from-into)							
male-male	30	40	28	29	28	34	27
male-female	8	1	9	9	9	4	10
female-male	2	4	1	1	1	1	1
female-female	4	3	5	5	5	5	5
% accuracy	77	90	77	77	77	89	74

TABLE 8. MC2 normal, jackknifed, and validation sample classification matrices

Matrix type	1	2	3	4	5	6	7
Normal (from-into)							
male-male	34	33	33	35	35	35	35
male-female	11	12	12	10	10	10	10
female-male	10	9	9	4	4	5	5
female-female	31	33	32	36	36	35	35
% accuracy	76	76	76	84	84	82	82
Jackknifed (from-into)							
male-male	34	32	33	34	34	34	33
male-female	11	13	12	11	11	11	12
female-male	10	9	9	5	5	5	5
female-female	31	31	32	35	35	35	35
% accuracy	76	75	76	81	81	81	80
Validation (from-into)							
male-male	31	28	29	29	29	26	29
male-female	9	11	9	9	8	11	9
female-male	1	0	1	0	0	0	0
female-female	5	6	5	6	6	6	6
% accuracy	78	76	77	80	81	74	79

TABLE 9. MC3 normal, jackknifed, and validation sample classification matrices

Matrix type	1	2	3	4	5	6	7
Normal (from-into)							
male-male	34	31	33	35	36	36	37
male-female	9	11	9	7	6	6	5
female-male	6	6	8	5	5	4	5
female-female	35	33	31	34	34	35	34
% accuracy	82	79	79	84	86	88	88
Jackknifed (from-into)							
male-male	33	31	32	34	35	35	34
male-female	10	11	10	8	7	7	8
female-male	6	6	8	6	5	7	6
female-female	35	33	31	33	34	32	33
% accuracy	81	79	78	83	85	83	83
Validation (from-into)							
male-male	28	30	27	26	27	26	26
male-female	9	6	8	9	9	9	10
female-male	0	0	0	0	1	0	0
female-female	6	6	6	6	5	6	6
% accuracy	79	86	80	78	76	78	76

TABLE 10. MC4 normal, jackknifed, and validation sample classification matrices

Matrix type	1	2	3	4	5	6	7
Normal (from-into)							
male-male	37	35	34	38	38	38	37
male-female	6	8	9	5	5	5	6
female-male	7	6	5	6	5	4	6
female-female	34	35	36	34	35	36	34
% accuracy	85	83	83	87	88	89	86
Jackknifed (from-into)							
male-male	37	33	33	36	38	37	35
male-female	6	10	10	7	5	6	8
female-male	7	6	6	6	6	6	6
female-female	34	35	35	34	34	34	34
% accuracy	85	81	81	84	87	86	83
Validation (from-into)							
male-male	34	32	33	32	30	32	32
male-female	6	6	5	6	8	6	7
female-male	0	0	0	0	0	0	0
female-female	6	6	6	6	6	6	6
% accuracy	87	86	89	86	82	86	84

in abbreviated form in Tables 7–11. The data presentation allows exact reconstruction of the classification matrices, while saving a considerable amount of space.

For MC1, the normal classification rate ranged from 82–86%, with jackknifing decreasing the accuracies to 78–86%. The cross-validation samples ranged from 77–90%. The best discrimination for MC1 was achieved using the isolated head function. For MC2, a different pattern was portrayed. The normal matrix accuracies ranged from

TABLE 11. MC5 normal, jackknifed, and validation sample classification matrices

Matrix type	1	2	3	4	5	6	7
Normal (from-into)							
male-male	35	31	36	37	31	35	36
male-female	5	10	4	4	9	5	4
female-male	5	6	6	6	6	7	6
female-female	34	34	33	33	32	31	32
% accuracy	87	80	87	88	81	85	87
Jackknifed (from-into)							
male-male	35	31	36	36	31	34	35
male-female	5	10	4	5	9	6	5
female-male	5	7	6	6	6	8	7
female-female	34	33	33	33	32	30	31
% accuracy	87	79	87	86	81	82	85
Validation (from-into)							
male-male	33	28	31	30	32	31	32
male-female	6	10	7	8	6	7	6
female-male	1	1	1	1	1	1	1
female-female	5	5	5	4	4	4	4
% accuracy	84	75	82	79	84	81	84

76–84%, with jackknifing decreasing the accuracy to 75–81%. The validation sample produced accuracies in the 76–81% range. For MC2 the isolated and combined articular end functions were poorer discriminators than the functions for relatively complete elements. MC3 exhibited a similar pattern of discriminatory power for the normal and jackknifed functions, where the articular end functions were poorer estimators of sex. However, the highest classification rate in the validation sample occurred for the isolated head function at 86%. MC4 exhibited the most consistent and highest classification rates, ranging from 81–89% in the calibration sample. Validation sample accuracies ranged from 82–89%, with the combined articular end function producing the best classification rate. MC5 exhibited a more random pattern, with the highest classification rate of 84% occurring for 3 of the 7 functions. Percent accuracies for all five elements ranged from 75–90%, with MC4 providing the most consistent discrimination in the mid-80% range.

DISCUSSION AND CONCLUSIONS

I have presented a total of 35 different linear discriminant functions which can be used to accurately predict the sex of an individual. While previous studies utilized similar measurements, the variety of functions presented in this paper allows for greater application of the technique without loss of accuracy. Both the previously published reports and the present paper return accuracies which generally fall in the 79–85% range. The newly generated functions utilized between 2–5 variables for each discriminatory function.

Another benefit of these functions is that they are generated from a truly modern sample, thus avoiding potential problems resulting from secular increases in metric dimensions (Meadows and Jantz, 1995). The trade-off for such an approach is that the sample sizes are smaller than ideal, particularly when having to draw calibration and validation samples from the original data set. While an alternative means for assessing accuracy in an unbiased fashion exists in the jackknifing procedure, it is impossible to exactly define the discriminant function used to obtain the classification matrix. Therefore, cross-validation with a random holdout sample is preferred. As stated above, the female validation sample is so small that true estimation of the error rate is difficult. This is due solely to the lack of female individuals in the UNM documented collection. Others have used a male-only validation sample and left the females essentially untested (Meadows and Jantz, 1992). The lack of populational differences is important, given the expected situations in which these functions will be utilized. However, it must be stressed that significant differences in population groups may occur in other samples. Nevertheless, with the growing literature on sex estimation (Scheuer and Elkington, 1993; Lazenby, 1994; Falsetti, 1995; Smith, 1996) and stature estimation (Musgrave and Harneja, 1978; Meadows and Jantz, 1992) using metacarpal dimensions, it is clear that these elements make an important contribution to forensic identification.

ACKNOWLEDGMENTS

The author thanks Dr. Joseph Powell for access to the UNM documented sample and his valuable advice on statistical matters. The comments of two anonymous reviewers also greatly improved this manuscript. Any errors, however, remain my sole responsibility.

LITERATURE CITED

Boas F. 1912. Changes in the bodily form of descendants of immigrants. Senate Document 208, 61st Congress, 2nd Session.

Falsetti AB. 1995. Sex assessment from metacarpals of the human hand. J Forensic Sci 40:774–776.

Lazenby RA. 1994. Identification of sex from metacarpals: effect of side asymmetry. J Forensic Sci 39:1188–1194.

Manly BFJ. 1994. Multivariate statistical methods: a primer. London: Rothman, Chapman, and Hall. p 112.

Mardia KV. 1970. Measures of multivariate skewness and kurtosis with applications. Biometrika 57:519–530.

Meadows L, Jantz RL. 1992. Estimation of stature from metacarpal lengths. J Forensic Sci 37:147–154.

Meadows L, Jantz RL. 1995. Allometric secular change in the long bones from the 1800s to the present. J Forensic Sci 40:762–767.

Musgrave JH, Harneja NK. 1978. The estimation of adult stature from metacarpal bone length. Am J Phys Anthropol 48:113–120.

SAS Institute. 1996. SAS/STAT user's guide, version 4, 4th ed. Cary, NC: SAS Institute, Inc. p 1686.

Scheuer JL, Elkington NM. 1993. Sex determination from metacarpals and the first proximal phalanx. J Forensic Sci 38:769–778.

Smith SL. 1996. Attribution of hand bones to sex and population groups. J Forensic Sci 41:469–477.

Wilkinson L, Blank G, Gruber C. 1996. Desktop data analysis with SYSTAT. Upper Saddle River, NJ: Prentice Hall. p 790.